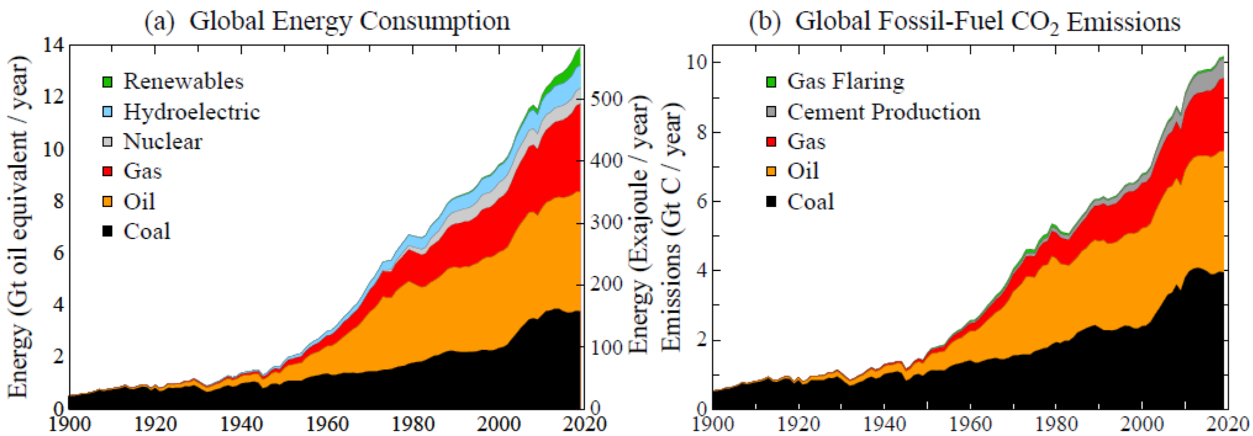

Fig. 43.1. Global energy consumption and fossil fuel CO_2 emissions.

Chapter 43. Energy for the World

Amory Lovins was the world's energy guru when he visited GISS in the late 1970s or early 1980s. He made a persuasive case for the potential of energy efficiency. All energy sources – fossil fuels, nuclear power, renewables – have impacts on the environment, so energy efficiency should be at the top of our priority list. I was duly impressed and asked for a copy of his charts.

Amory pointed out that government and industry projections of ever greater energy consumption in the United States were neither desirable nor likely to occur. Instead, he foresaw energy use peaking in the 1990s and then declining. "Soft" renewable energies – excluding large hydroelectric power – would steadily increase until about 2025 when soft renewables would be sufficient to fully supplant fossil fuels, nuclear power and large hydro in the U.S.

Decades later, Anniek and I were on the way to the Tallberg Forum in Sweden when we met Amory headed to the same place. It was a chance to compare our views on energy. My concern was the continued dependence on fossil fuels for about 80 percent of growing global energy consumption, which resulted in skyrocketing CO_2 emissions (Fig. 43.1b). Renewables include biofuels and biomass that are not all carbon-free, as we will discuss.

Amory's opinion was still that energy efficiency and soft renewables could power the world. He said that industry was leaving hundred-dollar bills lying on the ground by ignoring energy efficiency. Amory did not oppose a carbon fee or tax, but he said that it was unnecessary.

I believe that a near-global rising carbon fee is an essential underlying policy, if we want global CO_2 emissions to turn down rapidly. Dedicated nations might be able to reduce their emissions without a carbon fee, but one effect of such success is to reduce global demand for fossil fuels, thus keeping their price low. Fossil fuels are easy to dig up; if there is no global carbon fee, they will be cheap and someone, somewhere, will burn them.

A carbon fee and energy efficiency are not enough. The world demands energy to raise standards of living. If affordable carbon-free energies are not available, the world will continue to rely on fossil fuels. A sufficient rising carbon fee will spur innovations in clean energy, but that spur does not yet exist. Given the growing climate emergency, it is essential that governments also support clean energy research, development and demonstration (RD&D).

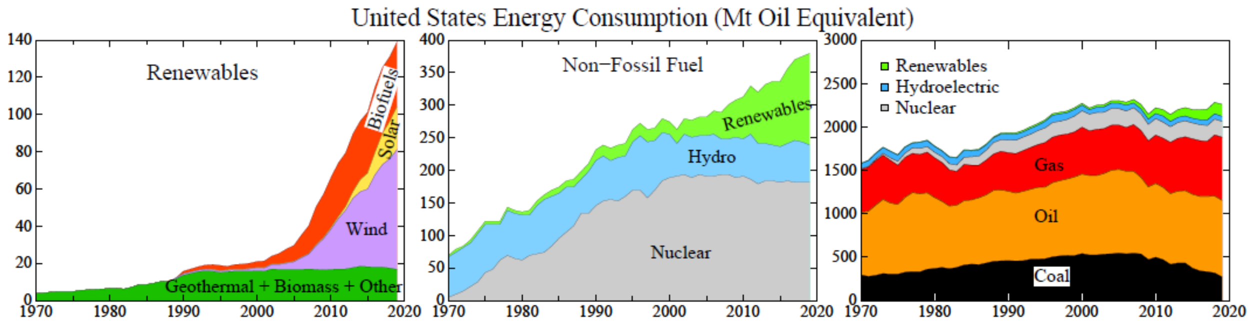

Fig. 43.2. United States energy consumption in megatons of oil equivalent.

I still had Amory's chart for U.S. energy consumption, which he made in the 1970s. His projection that U.S. energy consumption would change little was much better than government projections of rapid growth – actual energy use increased about 40 percent. However, his projection that soft renewables would provide most U.S. energy was way off. The U.S. was and is still powered almost 80 percent by fossil fuels.

I included a figure comparing Lovins' chart with actual data for the U.S. in my first book; an update of that figure is available.[1] A clearer depiction of all energy sources is provided by Fig. 43.2, which expands the vertical scale for renewables on the left, compares renewables with other carbon-free energies in the center, and compares all energy sources on the right.

Renewables are not in general carbon-free. Some biofuels (liquid bioenergy), such as ethanol from corn starch and biodiesel from soy or palm oil produce CO_2 comparable to fossil fuels; use of edible crops to make biofuels in general doesn't make sense. In contrast, algal biodiesel and ethanol from perennial grasses have much smaller carbon footprints. Biomass (solid bioenergy) fuels have a similar range. Biomass gathered from waste has a low carbon footprint and sustainably harvested bioenergy crops, e.g., from low-input high-diversity perennial grasses, may have a reasonably small carbon footprint. The carbon footprint of tree-based biomass fuels depends on the project design, ranging from potentially carbon-negative to worse than coal.[2]

Wind and solar energy are intermittent energy sources. Intermittency requires energy storage or a complementary variable energy source. Energy storage on the scale needed to make renewables our major energy source is dubious economically and it may be a global environmental quagmire, at least if it is achieved via popular lithium-ion batteries.

In reality, wind and solar energies are usually complemented by gas, which is almost as bad as coal for climate. Gas produces less CO_2 per unit energy than coal but it releases methane in the mining, transport and storage of the fuel. Moreover, gas is increasingly being obtained via fracking, which causes groundwater pollution.

Renewable energy can play an important role in our energy future, if it is limited to a fraction of total energy. But it needs to be complemented by clean carbon-free dispatchable energy.

Curiously, on 25 June 2008 while at the Tallberg Forum I received an e-mail from Tom Blees, who introduced himself and offered to send a preprint of his book, *Prescription for the Planet*.[3] Upon arriving home, I had time to pack fresh clothes, pick up Tom's book, and head to Tokyo and the United Nations University. I began to read Tom's book on the long return flight.

Tom Blees and Amory Lovins both have brilliant minds that have helped illuminate the global energy landscape. Their perspectives differ as day from night, yet they both make important contributions to the understanding that should affect our strategy for achieving a healthy climate.

Amory Lovins focuses on our cleanest energy source – negawatts, he calls it – the energy that is saved via increased efficiency. Sometimes he seems to imply that efficiency is all we need. Perhaps that's almost possible – in a rich country that is wasting most of its energy.

Tom Blees comes from the viewpoint that the world needs a huge amount of clean, affordable energy if we are to supplant fossil fuels. He holds up a ping-pong ball and notes that a ball of uranium of that size contains the energy used by an average American in a 100-year lifetime.

Blees is the sailor and author that I mentioned earlier. What are his nuclear energy credentials? He spent eight years researching the topic for his *Prescription* book under the tutelage of some of the best relevant minds in the world: George Stanford, Charles Till and Yoon Chang.

George Stanford was a nuclear reactor physicist who helped develop the integral fast reactor (IFR) at Argonne National Laboratory, a specific type of nuclear reactor that caught Blees' attention. Charles Till directed the IFR project at Argonne for a decade. Yoon Chang became the intellectual leader of continuing IFR research at Argonne.

Prescription for the Planet has imperfections that we recognize today, yet it was a brilliant effort to take a broad view of the energy and climate situation. The world needs abundant, clean, carbon-free energy to raise living standards and help us live with nature without destroying it.

Tom Blees' book made me realize that the world had no global energy strategy to solve the climate problem. IPCC had no such strategy. The Framework Convention provided no strategy. And Fig. 43.1 makes clear that without a strategy to rapidly phase down carbon emissions we are headed to hell in a handbasket.

George Stanford was a Yale University professor, retired from the Department of Energy's Argonne lab, when I was introduced to him. George patiently answered all questions. He was an expert in nuclear physics who could explain the physics quantitatively.

An important characteristic of the integral fast reactor (IFR) that Stanford and colleagues developed was its ability to utilize almost all of the energy in nuclear fuel. Most of today's nuclear power plants use less than one percent of the fuel; the rest remains in the nuclear "waste." Most of that waste is not really waste, it is fuel for a "fast" reactor, a reactor that allows neutrons to move fast enough to eventually fission almost all of the nuclear fuel.

George pointed out that available nuclear fuel is sufficient to provide all of the world's energy needs for billions of years, and that we do not need to mine uranium on land. We can "sieve" enough nuclear fuel from the ocean to last "forever" because uranium is continually leached from the ocean floor. Uranium extraction from ocean water has been demonstrated; it's more expensive than conventional mining, but it's a viable alternative. That puts nuclear energy in the same category as solar energy and wind energy – inexhaustible on any practical time scale.

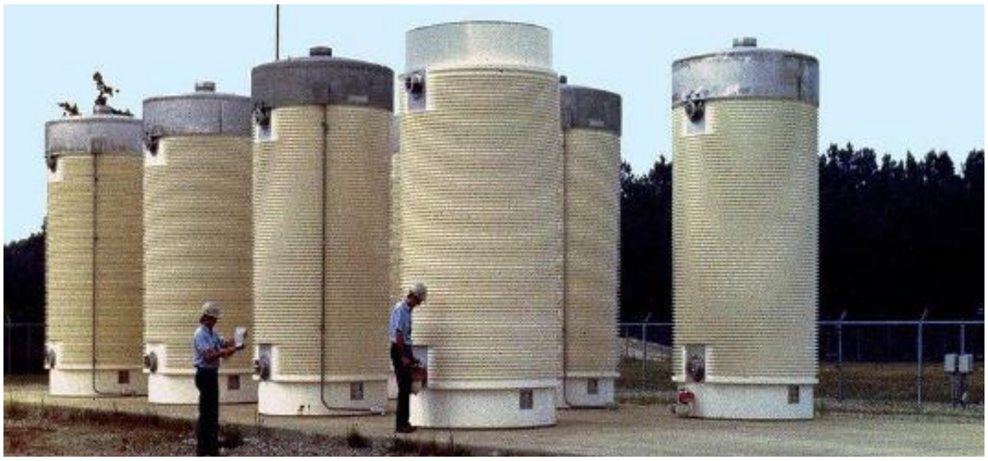

Fig. 43.3. Nuclear waste from a power plant, stored in dry cask containers.

Mention of "nuclear waste" almost perturbed the imperturbable George Stanford. First of all, he said, even if we never developed a fast reactor to utilize nuclear waste, the waste problem is much less for nuclear power than for any other major energy source. The basic reason for this is the high density of energy in nuclear fuel: the volume of waste is small. Nuclear waste today sits in containers where it harms nobody.

In contrast, fossil fuel waste is spewed into the air and spreads globally. The tiny aerosols damage the respiratory system and enter the blood stream, where they are a major cause of cardiac problems. Outdoor air pollution, much of it from fossil fuels, kills about 3.5 million people per year, which is about 10,000 people per day.[4] Indoor air pollution, mainly from fossil fuels and biofuels, kills a similar number. Yet these deaths are only a tiny fraction of the people suffering severe health problems from fossil fuel pollution.

Renewable energies are better than fossil fuels, but far from saintly. Solar panels contain high-toxicity heavy metals such as cadmium, chromium and lead, which never decline in toxicity because they are stable elements. Used or broken solar panels, even if disassembled for recycling, expose people to toxic elements, often people in poorer communities.

Batteries to complement renewable energy are an environmental issue. Required energy storage would be huge, implying humongous batteries. Required amounts of rare earths and heavy metals, if we make renewables our primary energy source, have the potential to create a large-scale problem at the mining sites and with disposal of used batteries. There is also explosive potential of so much stored energy.

The Oscar-winning filmmaker Michael Moore produced a documentary *Planet of the Humans* that notes damage to the natural environment from renewable energies. The film was released free on YouTube on Earth Day 2020, but backlash from the environmental community – heavily invested in renewable energies – forced YouTube to delete the film.[5]

Moore's film is dismal and pessimistic. In reality, we have a bright future if we put a rising price on carbon emissions and let alternatives compete: efficiency, renewables (wind, solar, bioenergy, geothermal), modern nuclear power, environmentally-friendly batteries, nuclear fusion, and many other options.

Figure 43.4. Humpback whale frolicking at Diablo Canyon nuclear power plant.

Nuclear energy has the smallest environmental footprint of all major energy sources. This advantage derives in part from nuclear energy density. This energy density allows nuclear power to produce a huge amount of energy from a single power plant covering a small area.

Nuclear power plants run most efficiently at full power. They can maintain that efficiency – while working in combination with intermittent renewable energy – by using excess energy to make liquid fuels, including hydrogen, or to desalinize water.

Nuclear power plants can be good neighbors. They provide good high-paying jobs and they have minimal effect on the environment. Whoa! That sounds wrong! Maybe, like the Black cowboy sheriff in *Blazing Saddles*,[6] I should point a pistol at my head and place myself under arrest for violating expected norms. Anyone who loves nature must oppose nuclear power, right?

Where the dickens did that concept come from? A clue is provided by a 1-minute film from an anti-nuke concert in New York City in 1979. Do the 200,000 people swinging and swaying to the words "give me the comforting glow of a wood fire, but please take all your atomic poison power away" realize that about 10,000 people per day die from indoor air pollution, more than have been killed by nuclear power plants in 50 years?

When I show that film clip, I am sometimes accused of making fun of environmentalists. No, I only want the audience to think. Do they really want to go back to stoking wood 24 hours a day? One person in the film clip says: "we need oil or coal, but certainly not nuclear." We live in Pennsylvania, where we are bombarded by slick advertisements critical of nuclear power, which include a note in small fading lettering: "Paid for by The American Petroleum Institute."

But nuclear radiation is strange and dangerous stuff! Really? Look at soot from fossil fuels in a microscope – now that's ugly! It should turn your stomach to realize that these tiny particles get into your lungs and blood stream, where they cause cardiac and pulmonary diseases.

Nuclear radiation – x-rays, gamma rays, alpha and beta particles – is the high energy end of the electromagnetic spectrum (Figure 6.1), beyond the UV. Nuclear radiation is ionizing, which means it's capable of knocking the electron off an atom. Too much ionizing radiation can damage human tissue, so we should avoid excessive radiation. However, life developed and is thriving on a planet bathed in nuclear radiation. Radiation is part of our everyday life.

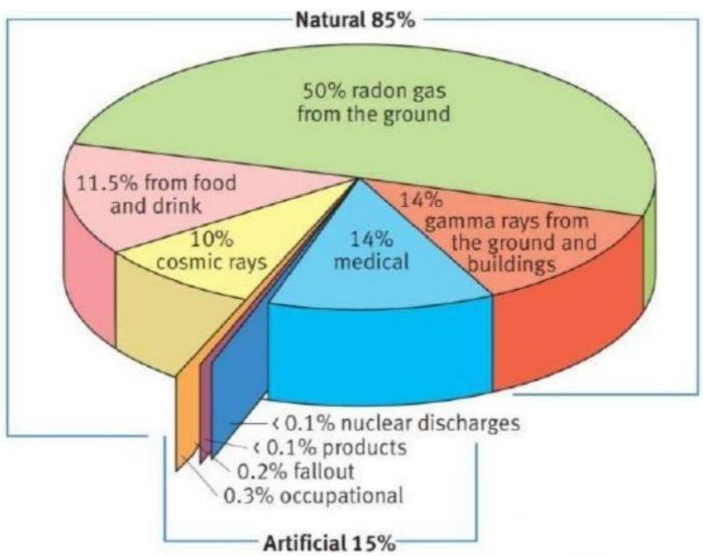

Figure 43.5. World-wide average annual background radiation is about 3 mSv.

Radiation comes from many sources. Figure 43.5 is an estimate of the background radiation that an average person on Earth receives annually. World average is about 3 milliSieverts (mSv) or 0.003 Sieverts. The Sievert is a measure of effective radiation dose that accounts for the type of radiation and its potential to harm human tissue. In this estimate, 85 percent of the background radiation is natural and 15 percent is human-caused.

Average exposure of a U.S. citizen is 6 mSv, because they receive annual diagnostic medical examinations averaging about 3 mSv. The effective dose in a CT scan is in the range 1-20 mSv.

Bananas, brazil nuts and many other fruits and vegetables are radioactive. On average we get about 0.3-0.4 mSv from our food and drink. Radon gas is our largest source of natural radiation.

Natural radiation levels vary geographically, for example, from about 2 mSv in the UK to 7 mSv annually in parts of Finland. Cosmic rays are twice as intense in Denver, compared with the rest of the U.S., because of Denver's greater altitude. Places such as Ramsar in Iran, Arkaroola in Australia, Guarapari in Brazil, and Yangjiang in China have natural radiation above 100 mSv.

High levels of radiation exposure, several hundred mSv or more, damage human tissue and organs, and cause acute radiation sickness. The 1986 Chernobyl nuclear power plant accident caused acute radiation sickness in 134 plant workers and firefighters who were exposed to radiation doses ranging from 800 to 16,000 mSv; 28 of those people died within three months.

A key question is whether low level radiation is harmful. Current regulations use the "linear no threshold" (LNT) assumption: any radiation is harmful, with harm proportional to radiation amount. LNT led the U.S. Nuclear Regulatory Commission (NRC) to require that the public not be exposed to more than 1 mSv per year above background.

The *Code of Federal Regulations* (10 CFR 20.1003) goes further: it requires radiation release to be "as low as reasonably achievable" (ALARA). In what may be a slight paraphrase, George Stanford said: "One mSv per year was a very stiff requirement, but we could design to it. No engineer can design to ALARA – its purpose seems to be to make nuclear power as expensive as possible."

Some scientists contend that tiny amounts of radiation are harmless – that there is a threshold level below which no harm occurs – or even that low dose radiation can be beneficial to human health.[7] They argue that low level radiation stimulates cell repair.

Why not compare cancer rates in different regions, with different background radiation levels? This has been done, but only to a limited degree. Theo Richel made a video[8] on Guarapari in Brazil, where people are exposed to radiation levels of more than 100 mSv, but scientific studies of the health effects of the Guarapari radiation are lacking.

Studies exist[9] of Ramsar, Iran, where radiation levels reach a few hundred mSv. There is no evidence of harmful effects, but the number of residents is too small for a significant conclusion.

The "Precautionary Principle" is the rationalization for the extreme ALARA radiation limit. This is consistent with the physicians' mantra: do no harm. Even if we are uncertain whether tiny amounts of radiation are harmful, the LNT assumption and ALARA make sense, right?

That depends. In the real world, people require energy. Should we not compare all energies to find those that cause *least* harm? Why do we not require minimal harm of all energies? If the same Precautionary Principle were applied to other energy sources, including fossil fuels, much of India, China, the U.S. and many other countries would need to be evacuated. I wonder where these several billion people would go?

It was sobering to realize that the world was winking at fossil fuel pollution, which kills thousands of people per day, while subjecting the nuclear industry to onerous limits. But it's what I learned over the next decade – about nuclear power and the reasons why society rejected nuclear power as a desirable energy source – that was staggering. That's for a later chapter.

We have a "planet in peril" said Presidential candidate Barack Obama. Could the U.S. begin to lead a serious effort to alter our planet's dangerous course? Obama promised that his election would be "the moment when the rise of the oceans began to slow and our planet began to heal."

Physics rules against such hyperbole. Earth's energy balance must be restored – an enormous task – before we can change the direction the planet is headed. However, the important thing was Obama's intent – if that was genuine, he needed to be well informed.

That was a good reason to pursue the workshop that I had discussed with Duke Energy (Jim Rogers) and PSE&G (Ralph Izzo). Discussions had lagged in the summer of 2008, which was a hectic period, as recorded on my web site. Rogers and Izzo wanted to delay the workshop until after the election. Their interest seemed to be to influence government policies that affected their utility businesses. They were happy with cap & trade, if the rules were favorable.

I wanted a workshop on our terms before the election, but I had no time, so Pushker Kharecha, my close colleague at GISS, took responsibility for workshop organization. We could have a mini-workshop before the election and consider the possibility of a bigger conference later.

We wanted to define national policies that could be an example for effective global policies, which implied a focus on phasing out coal emissions as rapidly as possible in a way that led to continued phasedown of other fossil fuel emissions. We wanted to challenge cap & trade – with the fee & dividend alternative – and we wanted to consider the feasibility of a low-loss national grid to admit more widespread sharing of intermittent renewable energies. Chuck Kutscher of the National Renewable Energy Laboratory helped us define the workshop program.

Our "Climate and Energy" workshop was held at the Washington Court Hotel, near the U.S. Congress, on 3 November 2008, the day before the election. Several Congressional staff members attended. Workshop topics and conclusions are described in a peer-reviewed paper.[10]

Our workshop sessions were on energy efficiency, renewable energies, the national electric grid, nuclear power and carbon capture. Each session was defined with the help of and led by the top U.S. expert in the field, respectively Ed Mazria, Chuck Kutscher, Steve Hauser, Ernie Moniz and Ed Rubin. Ernie Moniz was the only one unable to attend the workshop.

We concluded that elimination of U.S. carbon emissions from coal by about 2030 was feasible, but it required improved energy efficiency, a national "smart grid," improved energy storage capability, and advanced nuclear power. However, the underlying requirement for a clean emissions-free future was a substantial rising price on carbon emissions.

After a long day at the workshop, I took the train to Newark, New Jersey and drove to our home in Bucks County, Pennsylvania. The next morning, I got up early to cast my vote for Barack Obama. It was exciting. I believed that, even if Obama did not understand the policies that were needed to address climate change, he would surround himself with advisers who did know.

The setting was the same as election evening 2004 – again I had butterflies in my stomach as we settled down to watch election results come in. The results in 2008 could not have been in starker contrast to those in 2004. As it became clear that America was electing Barack Obama – a brilliant African-American – as our next President, I had tears in my eyes. We could again be the shining city on a hill, leading the world to a bright future. So I thought.

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[1] Figure 2 in Hansen, J., 2009: Storms of My Grandchildren, Bloomsbury, New York, 320 pages. An update of the figure is available at http://www.columbia.edu/~mhs119/UpdatedFigures/
[2] Roder, M., C. Whittaker and P. Thornley, How certain are greenhouse has reductions from bioenergy? Life cycle assessment and uncertainty analysis of wood pellet-to-electricity supply chains from forest residues, Biomass and Bioenergy 79, 50-63, 2015.
[3] Blees, T., *Prescription for the Planet*, Create Space, 375 pp., 2008. Free pdf at http://thesciencecouncil.com/ His book largely advocates the IFR technology. My response to him from Tallberg was "I will be happy to be convinced that a solution for the nuclear portion is within reach – so I look forward to a better understanding of that. I do not expect that (nuclear) technology to eliminate the need for a low-loss national grid. The latter is needed for renewable energies to become major players. But nuclear power will also become much more effective, if the generation can largely occur in existing and rather remote locations."
[4] World Health Organization, 2018, https://www.who.int/airpollution/data/en/ accessed 21 December 2020.
[5] But as of today(24 December 2020) it is available at https://planetofthehumans.com/
[6] *Blazing Saddles* is a 1974 American satirical Western comedy film directed by Mel Brooks and starring Cleavon Little and Gene Wilder.
[7] Cuttler, J.M., Application of low doses of ionizing radiation in medical therapies, *Dose-Response*, Jan-Mar, 2020.
[8] Richel, T., No more radiophobia, 2019.
[9] Dobrzynski, L., K.W. Fornalski and L.E. Feinendegen, Cancer mortality among people living in areas with various levels of natural background radiation, *Dose-Response*, July-September, 2015.
[10] Kharecha, P.A., C.F. Kutscher, J.E. Hansen, and E. Mazria: Options for near-term phaseout of CO_2 emissions from coal use in the United States. *Environ. Sci. Technol.*, **44**, 4050-4062, 2010.